

DARPA pre-baa workshop on Meta-materials
September 29, 2000

Applications of Meta-Materials to DoD Electrical Power Systems

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Office of Naval Research

- Use of electrical systems in DOD platforms is projected to increase dramatically

- **Power Electronics** performance, reliability, and flexibility must improve to meet requirements

Electric-Drive Ships

- Reconfigurable
- Increased survivability
- Power balancing
- Flexibility in ship architecture
- Automation
- New capabilities:
 - Electric launch and recovery systems

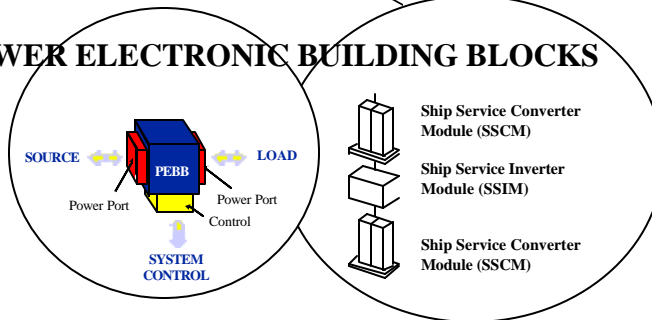
ELECTRICALLY RE-CONFIGURABLE SHIP ENHANCED WARFIGHTING PERFORMANCE

FUEL CELL

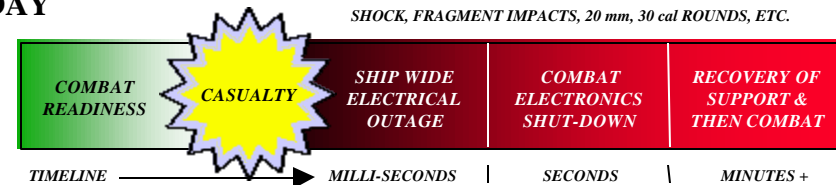
POWER GENERATION MODULE

ZONAL ELECTRICAL DISTRIBUTION SYSTEM

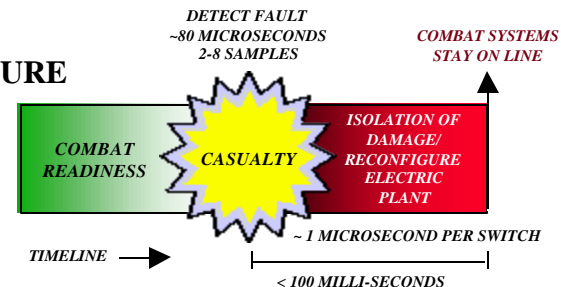
POWER ELECTRONIC BUILDING BLOCKS



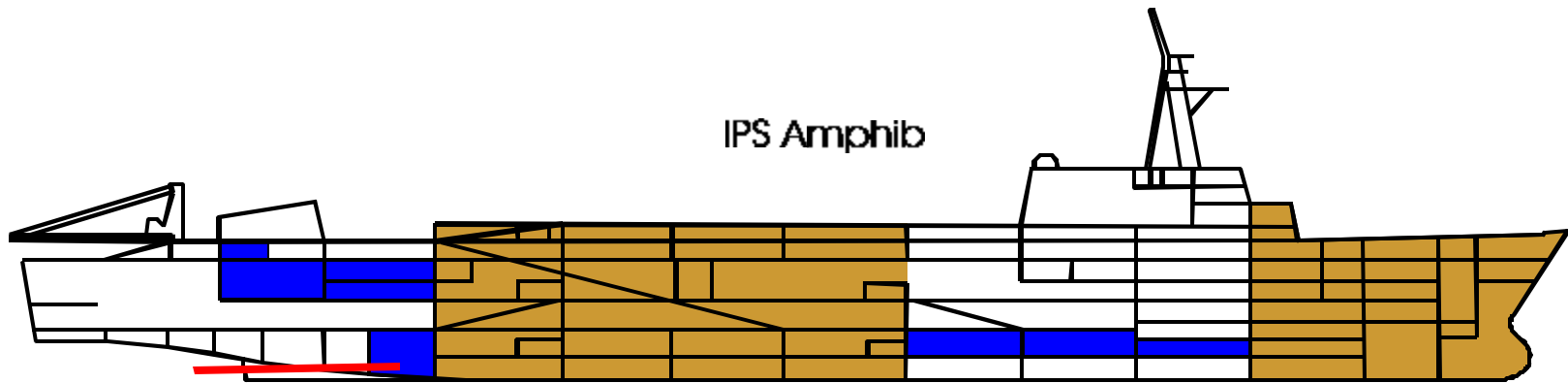
TODAY



FUTURE



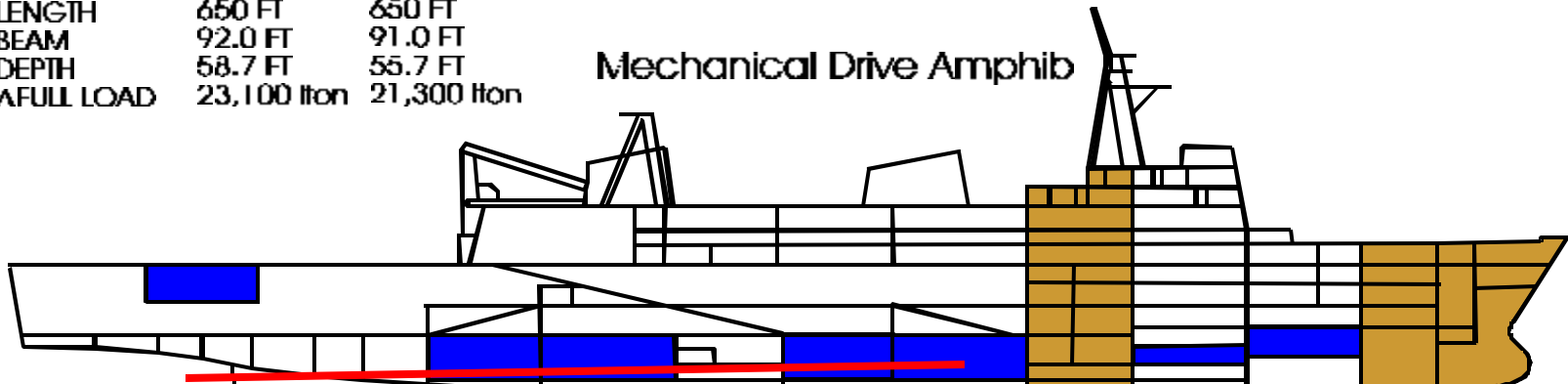
Architectural Flexibility



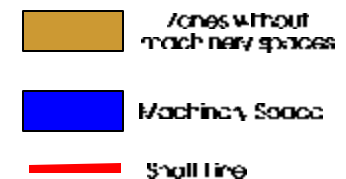
CHARACTERISTICS

	Mechanical Drive	IPS
LENGTH	650 FT	650 FT
BEAM	92.0 FT	91.0 FT
DEPTH	58.7 FT	55.7 FT
A FULL LOAD	23,100 ton	21,300 ton

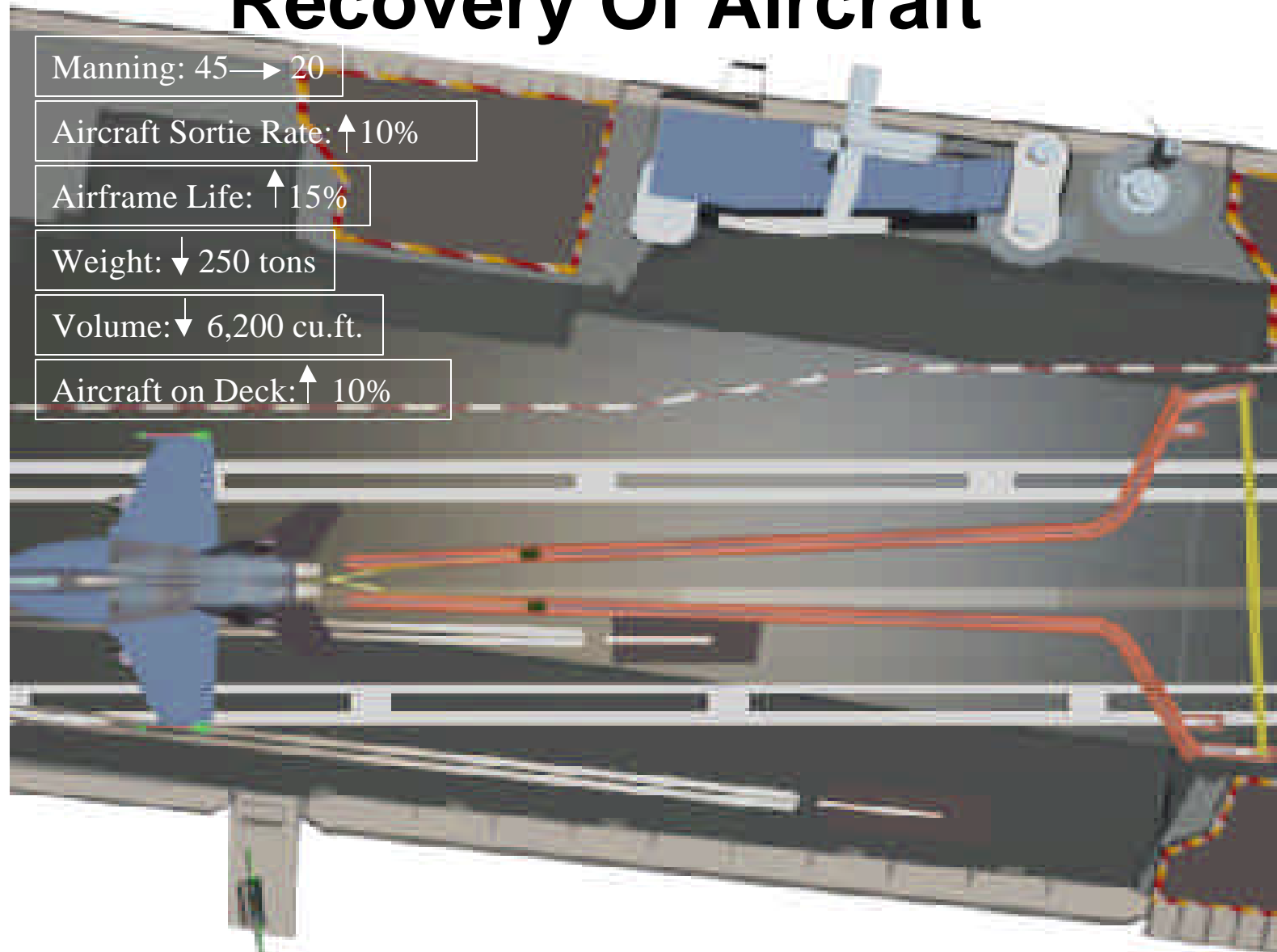
Mechanical Drive Amphib



Short Shaft Lines
Vertical Integration



Linear Motor Technology for The Recovery Of Aircraft

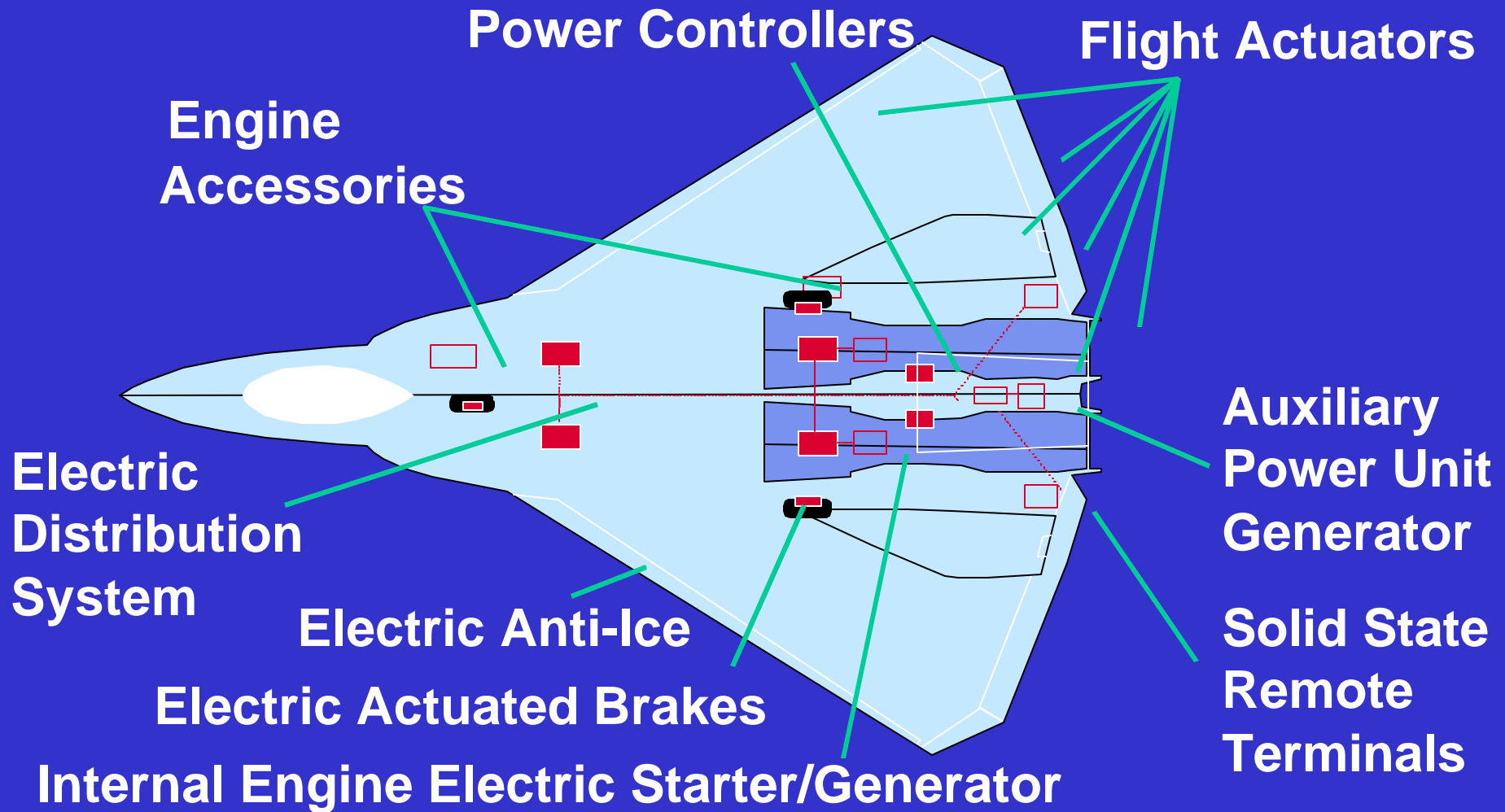


More Flexible Future Aircraft & Ship Designs

More Electric Airplane

- Survivability
- No hydraulics, no fluid disposal problems
- Integrated starter-generator
- Electric-control actuators

“More Electric Aircraft”



Hybrid-electric ground vehicles

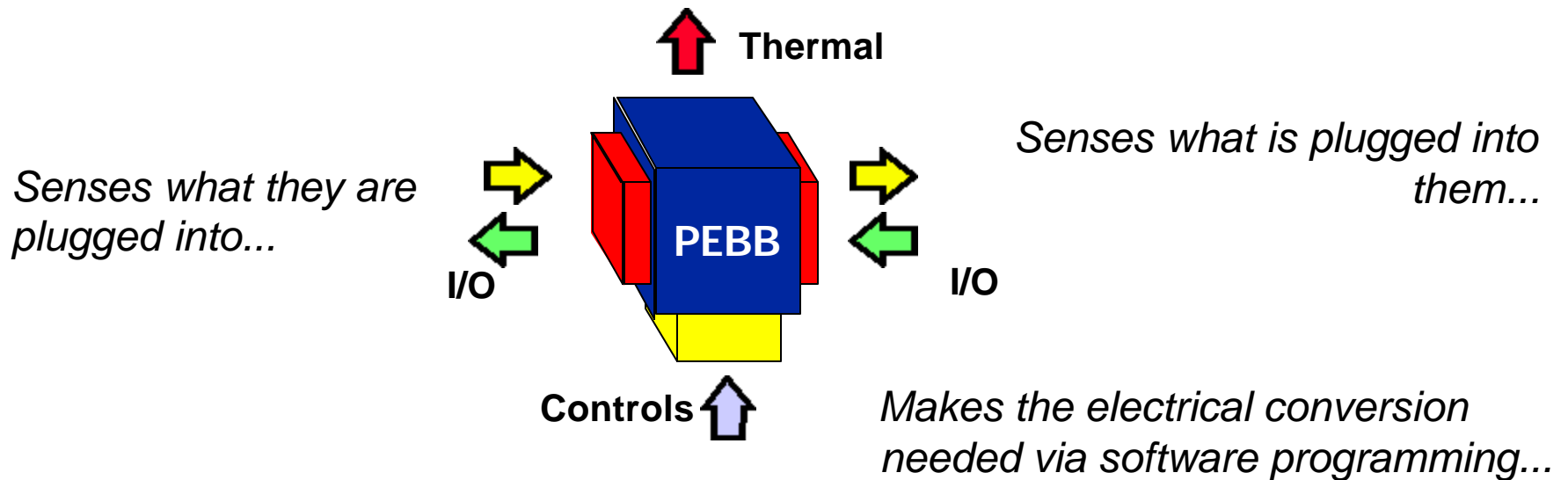
- Survivability
- Stealth
- Increased range
- New capabilities
 - Pulsed power weapons/defenses

Navy Advanced Electrical Power Systems Program

- Modular architecture (a la microelectronics)
- Standardized interconnects
- Standardized, programmable controls
- Reduced cost, improved logistics
- DC-400 Hz output
- 50kW to MW power
- 20kHz or higher Switching frequency

Power Electronic Building Blocks (PEBB)

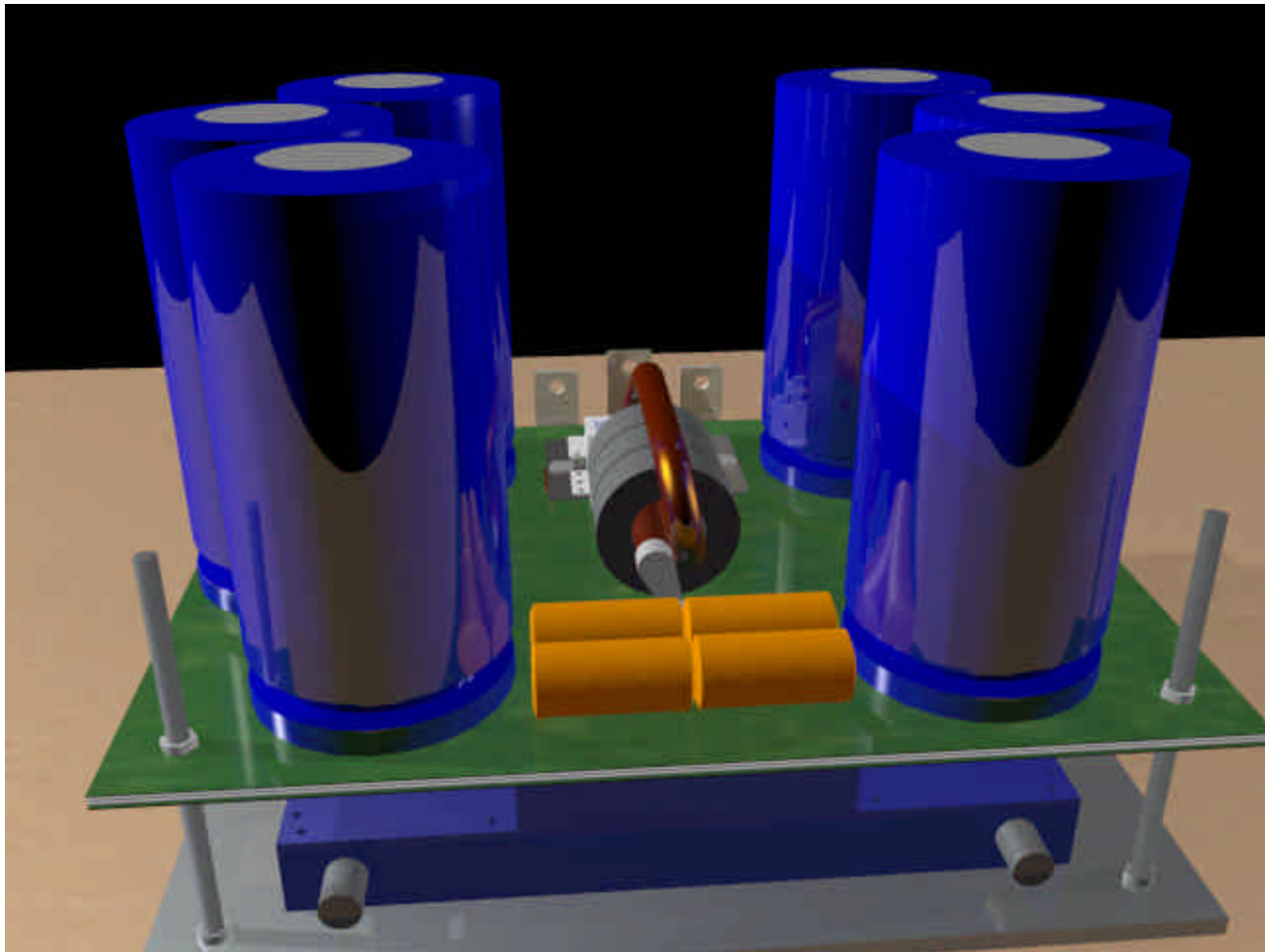
are a set of blocks that:



A UNIVERSAL POWER PROCESSOR. Changes any electrical power input to any desired form of voltage, current and frequency output.

<http://pebb.onr.navy.mil>

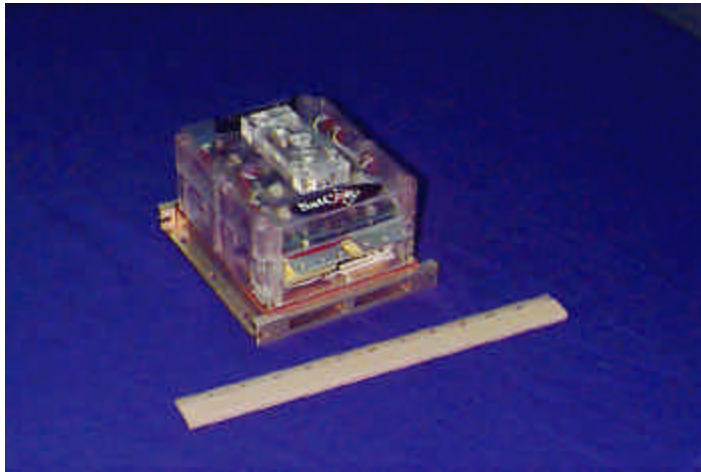
VTB: The Virtual PEBB



PEBB CONCEPT DEMONSTRATIONS

(ALL 3 CONCEPT DEMONSTRATORS EXCEED THE PEBB-3
VOLUMETRIC GOAL OF 50KW/FT³)

50kW, 3-phase inverter by SATCON
(~400 kW/ft³ or ~14.1MW/m³)



250kW, single phase leg of a 3-phase
multi-level inverter by VPI&SU (200-
250 kW/ft³ or 7.1 – 8.8 MW/m³)



250kW, single phase leg of a 3-phase inverter by
DNSWC/Harris (60 - 80 kW/ft³ or 2.1 – 2.8 MW/m³)

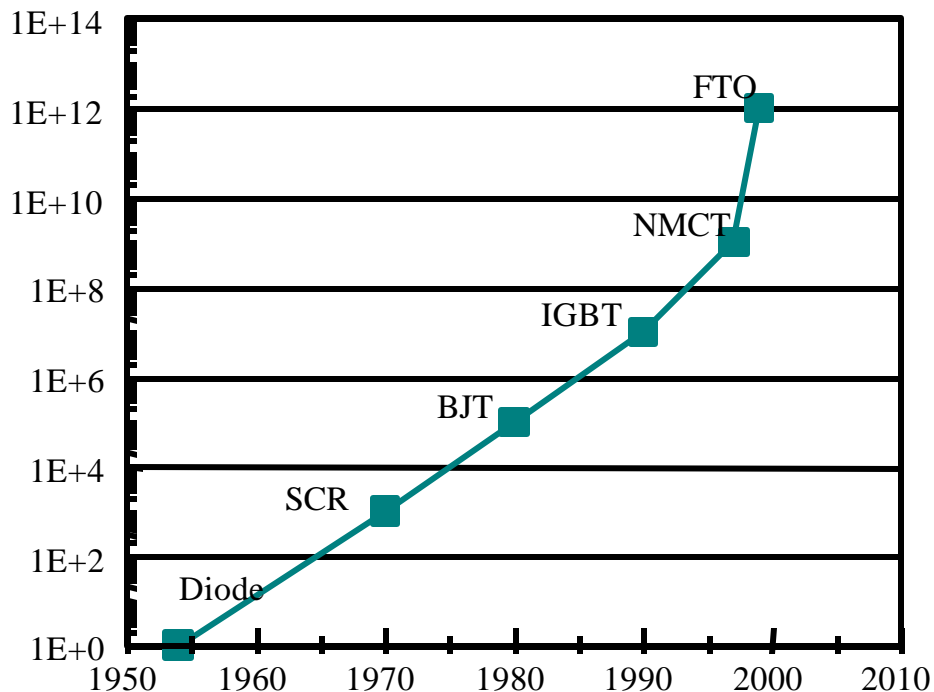
**>10x
Improvement in
size and weight**

Component technologies for power electronic modules

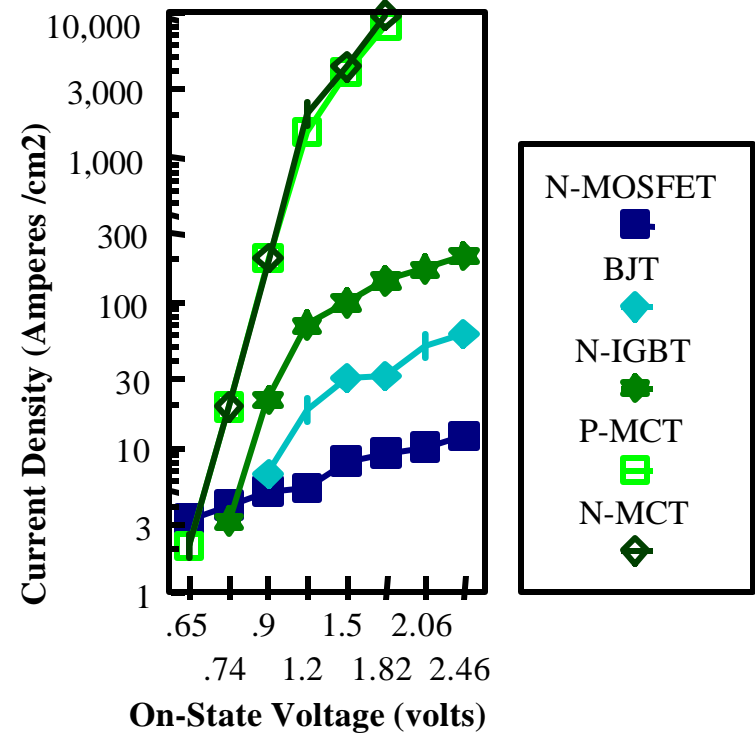
- Semiconductor switches
- Programmable controller
- Thermal management, Electrical Isolation and other packaging technologies
- Input (DC) bus capacitor
- Resonant capacitor(s) and inductor
- Output (AC) filter capacitor(s) and inductor

TRENDS IN POWER SEMICONDUCTOR DEVICES

Current density, voltage, speed, reliability, and cost



Theoretical on-state voltage



**7 orders of magnitude over the last 40 years
5 orders of magnitude over the next 5 years**

MCT/IGBT solid state switching

Increased current switching (300 A - IGBT)

Increased voltage (1700 V - IGBT)

Increased frequency (70 kHz - MCT)

Pulse Width Modulation (PWM)

- Eliminates harmonic distortions – noise
- Clean DC transmission

High Frequency Synthesis

HIGH FREQUENCY = SMALL FILTERS = REDUCED SIZE & WEIGHT

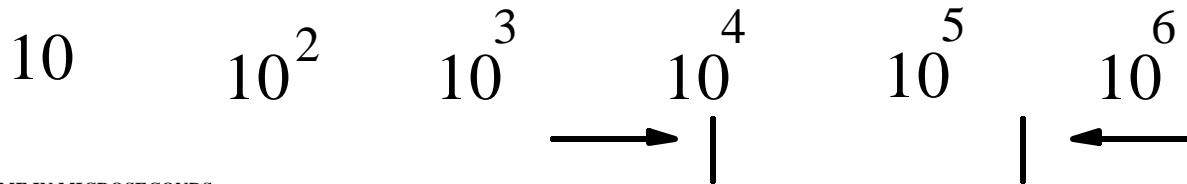
HIGH FREQUENCY = MULTI-FUNCTION EQUIPMENT = IMPROVED SYSTEM PERFORMANCE

**2/3 OF THE SIZE OF
TYPICAL NAVY
EQUIPMENT IS
FILTER-
resulting from 3% THD
spec.**

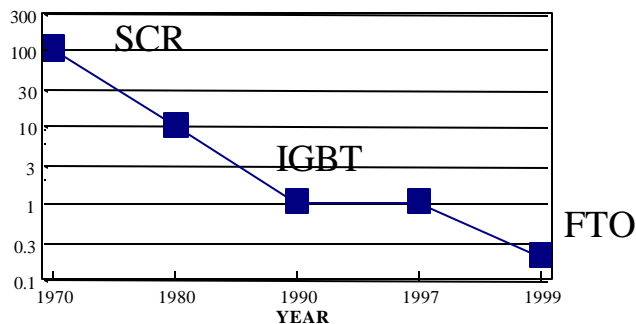
**DESIRED
FUNDAMENTAL**

**SWITCHING
FREQUENCY**

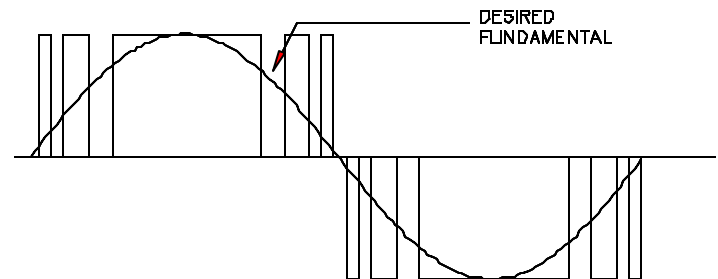
**NEED
FASTER
SWITCHES**



TURN-OFF TIME IN MICROSECONDS



FREQUENCIES TO BE FILTERED



Capacitors and Inductors

- **Input (DC) bus capacitors**

- Counteract switching transients, maintain bus voltage (1000 V)
- Store energy, could be non-linear
- $C=4000 \mu\text{F}$

- **Resonant capacitor and inductor**

- Set resonant frequency higher than switching frequency (X10 ideally)
- $C=1 \mu\text{F}$, $L=1 \mu\text{H}$
- $V=1000\text{V}$, $I=800\text{A}$ peak

- **Output (AC) filter capacitor and inductor**

- Filter out switching frequency harmonics from output (10 to 400 Hz)
- $C=50 \mu\text{F}$, $L=150\mu\text{H}$, nominal
- $V\sim 500\text{V}$, $I\sim 500\text{A}$

Capacitor Materials Wish List

- High CV product
- Linear, stable dielectric curve
- Smaller size, lighter weight
- Temperature stability (-55C to 85C)
- Low ESR, ESL (parasitics)
- High surge capability -- self-healing

Inductor Material Wish List

- High permeability
- Linear B-H, non-saturating
- Zero hysteresis, low losses
- Light weight, comformable
- Mechanically rugged
- Temperature stability (-55C to 85C)

Meta-materials for Power Electronics

Combine properties in new ways:

Dielectric or magnetic function +
Thermal conductivity +
Mechanical strength

Provide circuit designers with new options